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Abstract: OBJECTIVE When investigating dose-response relationships in rehabilitation studies, dose is often equated with duration of therapy. However, according to the American College of Sports Medicine, dose consists of the factors frequency, intensity, time and type. Thereby, especially quantification of intensity needs improvement to have a more precise estimate of the dose. Thus, the aim was to investigate the intensity during mobility-focused, real-life pediatric rehabilitation therapies. DESIGN Eleven participants (5 girls; 12.5±2.1y old) with neurological disorders and independent mobility wore accelerometers at wrists and ankles and a portable heart rate monitor during several of the following therapies: sports therapy, mobility-focused physiotherapy, medical training therapy, and robot-assisted gait training. Intensity of physical activity was quantified by activity counts (measured via accelerometers) and heart rate. RESULTS Therapy duration did not correlate with intensity. At the same time we found significant differences between intensities of different therapies. CONCLUSION Different therapies elicit different levels of intensity in children with neuromotor disorders. Heart rate and activity counts are suited to estimate the intensity of a therapy and provide complementary information. We recommend against using the duration of a therapy as a proxy for the dose to make statements about dose-response relationships.

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Pediatric rehabilitation therapies differ in intensity: Pilot study to highlight the implications for dose-response relationships

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Abstract

Objective When investigating dose-response relationships in rehabilitation studies, dose is often equated with duration of therapy. However, according to the American College of Sports Medicine, dose consists of the factors frequency, intensity, time and type. Thereby, especially quantification of intensity needs improvement to have a more precise estimate of the dose. Thus, the aim was to investigate the intensity during mobility-focused, real-life pediatric rehabilitation therapies.

Design Eleven participants (5 girls; 12.5±2.1y old) with neurological disorders and independent mobility wore accelerometers at wrists and ankles and a portable heart rate monitor during several of the following therapies: sports therapy, mobility-focused physiotherapy, medical training therapy, and robot-assisted gait training. Intensity of physical activity was quantified by activity counts (measured via accelerometers) and heart rate.

Results Therapy duration did not correlate with intensity. At the same time we found significant differences between intensities of different therapies.

Conclusion Different therapies elicit different levels of intensity in children with neuromotor disorders. Heart rate and activity counts are suited to estimate the intensity of a therapy and provide complementary information. We recommend against using the duration of a therapy as a proxy for the dose to make statements about dose-response relationships.

Keywords: Accelerometry, physiological phenomena, neurologic gait disorders, child

Introduction

The dose-response relationship of therapeutic interventions during rehabilitation of neuromotor disorders is an important aspect of clinical trials. Cortical reorganization after motor training has been shown to happen in animals[1] and humans[2], and meta-analyses[3,4] point towards a positive dose-response relationship. But how is the dose of interventions exactly determined? The following factors of such non-pharmacological therapies are thought to play a crucial role when it comes to adaptations of the nervous system[5–7]: Type (the type of exercise that is performed), frequency (the number of sessions a week and number of weeks), intensity (how strenuous the exercise is at each session), and time (the amount of time per session).[8–10] Nevertheless, the dose is often still equated with the total duration of therapy intervention[4,11,12], even though this might be misleading[13], since the duration of a therapy is not necessarily an adequate proxy for its content.[14] Yet, the total duration of therapy intervention is still often the only metric that is being reported in rehabilitation studies.[7] However, a rehabilitation stay should be looked at in a more differentiated way, for instance with the 4 established key parameters (i.e. type, frequency, intensity, and time).[8] Thereby, objective information is especially necessary for the parameter intensity, which is obviously the most challenging parameter to capture in practice. Furthermore, observations from rehabilitation settings in real-life situations are needed, as these often have other objectives than clinical studies.[14] Currently, there is a paucity of studies in this field. Host et al. have developed the measure of Patient Active Time and used this to successfully differentiate between a standard of care intervention and a high-intensity intervention in post-acute geriatric rehabilitation.[15] Choquette et al. showed that the intensity of a therapy can be successfully measured by accelerometers. In the field of pediatric neurorehabilitation, there are no comparable studies to date.

With this observational pilot study, we want to provide a closer look at the key parameter of intensity in a pediatric rehabilitation setting. The primary aim was to investigate the intensities of activity-promoting therapies (as measured via activity counts and heart rate) and the correlation between intensity and therapy duration. The secondary aim was to assess if the functional level of a participant had an influence on the exerted intensity of a therapy.

Methods

Participants

A convenience inpatient sample was recruited at the Rehabilitation Center of the Children's Hospital Zurich in Affoltern am Albis. Recruitment of participants and data collection took place from January to July 2016. Inclusion criteria were: (1) children with neurological disorders aged 5-17 years, (2) cognitive ability to understand basic verbal instructions, (3) no aggressive or harmful behavior, (4) independent mobility (walking or active wheelchair), (5) permission of a physician to perform a graded exercise stress test, and (6) written informed consent of legal guardians and adolescents ≥14 years or assent of children <14 years, respectively. The study was approved by the Cantonal Ethics Committee of Zurich, Switzerland. To guide the reporting of this cross-sectional study, the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist was used (see Supplemental Digital Content 1, http://links.lww.com/PHM/A893).

Protocol

We used a cross-sectional, multiple measures study design. The protocol consisted of an assessment part and the measurement of two sessions of at least three activity-promoting therapy modalities that our rehabilitation center offers:

i) Robot-assisted, bodyweight-supported treadmill training: These trainings were done with the pediatric Lokomat (Hocoma AG, Volketswil, Switzerland) which consists of an exoskeleton that can be adjusted to the participant, a dynamic bodyweight-support system, and a treadmill.[16] The Lokomat orthosis was adjusted individually to each participant according to clinical standards.[17] Effective training duration without donning and doffing was 30 min.

ii) Medical training therapy (MTT): This training focuses on strength, endurance and coordination exercises and lasts 30 min. One lesson usually starts with endurance exercises on devices like rowing or cycling ergometers, crosstrainers or treadmills. This is followed by an individualized program of isolated and functional strength exercises (with dumbbells, cable pulls, wall bars, resistance bands, etc.) and coordination exercises (coordination ladders, trampolines, balance boards and balls, etc.).

iii) Locomotion-based physiotherapy: This therapy primarily focuses on the quality of walking and walking-related movements and on regaining or improving functions and activities of daily living. This therapy lasts 45 min and is highly individualized and as such probably the most heterogenous therapy.

iv) Sports therapy – Plusport: This is a multi-sportive training, e.g. in the form of circuit training and games, conducted in the gym. It is a group therapy and lasts 60-75 min.

v) Sports therapy – Run&Fun: This therapy consists of playing and running exercises, such as team sports, relays or pendulum runs, for participants that can walk without assistive devices with the focus on endurance. The lessons take place in the group, outdoors and last 45 min.

These are all therapies that pose at least some challenge to the cardiovascular system which is the reason why they were preselected for this study. Due to the observational nature of the study, the order of the therapies, in which participants were measured, was determined by the rehabilitation schedule of the participants. A separate appointment was made for the assessment part. The whole protocol was expected to be completed within 2 weeks for each participant. No therapy sessions were recorded on the day of the assessment. For a participant to be included into data analysis, participation in at least three different activity-promoting therapies was necessary.

Assessments

The assessments took place early in the morning without prior exercise. To determine resting heart rate, the participant's heart rate was recorded while lying at rest for 15 min using a portable heart rate monitor. The mean of the values at minutes 12, 13, 14, and 15 was used as resting heart rate.[18] To gather information about the functional mobility level of the participant, we performed three assessments.

- The Gross Motor Function Classification System (GMFCS) is based on self-initiated movement, with an emphasis on sitting, transfers, and mobility.[19] The GMFCS was also used to investigate differences in intensity between different functional levels. Even though the GMFCS has not been validated for patients with diagnoses other than CP, for the purpose of this study it was determined for every participant.[20]
- The Functional Ambulation Category is a functional walking test that determines how much personal assistance a patient requires.[21]
- The 10 Meter Walk Test[22] was performed at preferred speed. With those unable to walk, a One Stroke Push Test was conducted, where participants were required to propel the wheelchair forward by pushing once with maximal effort. The outcome was the distance covered.[23]

Shuttle Run Test and Shuttle Ride Test

To determine maximal heart rate, we used a Shuttle Run Test, which is a multi-stage test measuring aerobic fitness. We used four adapted versions for children with CP (GMFCS levels I to IV)[24–26] which are described in Table 1. It has been shown that these protocols are valid and reliable to assess cardiorespiratory fitness.[24–26]

Participants wore a portable heart rate monitor, and, if necessary, they used their personal orthoses, walking device or wheelchair. The participants walked, ran or wheeled between two markers bounding a 10-meter course (marked with cones and duct tape). Those with a walking device walked along a 5-meter square (marked with cones). Participants were paced by an acoustic signal. In the beginning, they were accompanied by a human movement scientist to help them adjust their speed to the signal. Every level lasted 1 minute. After each level, the time interval between the beeps decreased, and the participants had to speed up. The test ended when participants were more than 1.5 m away from the marker on two consecutive occasions (1 m for protocol III).[24–26] Heart rate at test abortion was then noted.

The test was considered maximal if the participants met the objective criterion of a peak heart rate of ≥180 bpm and two out of the following subjective criteria: unsteady running/walking/propelling, sweating, facial flushing or clear unwillingness to continue in spite of strong verbal encouragement.[26] If the test was maximal, the achieved heart rate was used as maximal heart rate for further calculation. If the test was not maximal, a value of 194 bpm was used instead, as this approach has been shown to be more accurate compared to the widely known “220 minus age”-equation.[27]

Measurements

Activity counts

Activity counts during therapy sessions were assessed with four ReSense inertial measurement units (IMU, Rehabilitation Engineering Lab, ETH Zurich, Zurich, Switzerland, sampling frequency: 50 Hz). These are miniature-sized wearable modules, which contain a 3-axes accelerometer, a 3-axes gyroscope, and a barometric pressure sensor. They were developed for precise long-term measurements of physical activity.[28] Participants wore one IMU at each wrist and one at each ankle.

Heart rate

Heart rate during therapy sessions was assessed with the Polar RS800CX (Polar, Kempele, Finland) with a sampling frequency of 1 Hz.

Data processing

Activity counts

Accelerometer data of all three axes were used to calculate activity counts and they were quantified per minute. Synchronization of the IMUs as well as data download was done with the ReSense Connect software (Rehabilitation Engineering Lab, ETH Zurich, Zurich, Switzerland). All further data analysis was done with Matlab (version R2015a, Mathworks, Natick, MA, USA). Thereby, we deleted all recorded samples outside of the actual therapy session (participants clapped 5 times at the beginning and end of each therapy session). Then, activity counts were computed as follows:

$$\mathrm{AC(t)} = \sum_{t=t_{start}}^{t_{end}} \sqrt{a_x(t)^2 + a_y(t)^2 + a_z(t)^2}$$

t = 60sec

AC: activity counts; $a_{x,y,z}$: acceleration in x, y, z direction

The effects of gravity were neglected since they are approximately the same in all conditions.

Heart rate

Children are characterised by large inter-individual variability in maximal heart rate.[29] Accordingly, also the absolute HR may present large differences. To enable comparison across participants and between therapies, relative heart rate (= recorded heart rate / maximal heart rate of the child) was calculated for every minute during therapies.

Analyses and statistics

Due to the small differences between sides, activity counts for the left and the right side were concatenated, but separately analyzed for the arms and legs. To investigate the relationship between therapy duration and intensity, Pearson correlation coefficients were calculated per therapy for the activity counts of the arms, the activity counts of the legs and for relative heart rate. Due to the small number of participants and their clinical heterogeneity, a quantitative comparison of the intensity of all therapies was not possible. Accordingly, two comparable groups were formed. One group consisted of children that all visited robot-assisted gait training, MTT, and physiotherapy (N=8; IDs 1, 2, 6, 7, 9, 10, 11, 12; median GMFCS level II) and one group consisted of children that all visited MTT, PluSport, and Run&Fun (N=4, IDs 4, 5, 7, 8; all GMFCS level I). Differences between the therapies (fixed factor) within the 2 groups were tested with 2-way analyses of variance for repeated measures for the activity counts of the arms, the activity counts of the legs and for relative heart rate (dependent variables, all minute values were included for both repetitions of each therapy) with a Bonferroni correction for multiple comparisons. To estimate the effect sizes, partial Eta-squared (η_p^2) was calculated and interpreted according to the following cut-off points: 0.01 ~ small, 0.06 ~ medium, and >0.14 ~ large.[30]

Testing for normal distribution was done with the Shapiro-Wilk test. IBM SPSS (version 25.0, SPSS Inc., Chicago, IL, USA) was used for all analyses. Alpha was set at 0.05.

Differences between functional levels during Medical Training Therapy

For the data from MTT, which all participants attended, a 2-way analysis of variance for repeated-measures was performed for the activity counts of the arms, of the legs as well as for relative heart rate (dependent variables) to investigate differences between GMFCS levels (fixed factor) with a Bonferroni correction for multiple comparisons.

Results

Fifteen inpatients were asked to participate. Three of them refused due to lack of motivation and one was excluded due to a lacking medical permission for the exercise stress test (ID03). In the end, 11 children and adolescents aged 9 to 16 years (5 girls, 6 boys; 12.5±2.1 years (mean±standard deviation)) participated in the study and they were measured during an average of 6.5±1.3 therapy sessions. Participants' characteristics are listed in Table 2. An overview of the measured therapies, missing data due to technical problems as well as delays of measurements are shown in Supplemental Digital Content 2 (http://links.lww.com/PHM/A894).

<u>Relation between therapy duration and intensity</u>

Figure 1 shows scatterplots for the intensity measures (activity counts of the arms, activity counts of the legs and relative heart rate) per therapy. Only Run&Fun showed a significant negative correlation between therapy duration and intensity.

<u>Differences among various therapies</u>

Figure 2 gives an overview of the intensity during different therapies separated for the activity counts of the arms, the activity counts of the legs, and for relative heart rate. It shows the average intensity (activity counts and heart rate) per available training modality for each participant relative to the intensity of MTT of the same participant.

Robot-assisted gait training vs. MTT vs. physiotherapy (N=8)

Table 3 shows the average intensity values of all therapies as analyzed in both subgroups. Analyses of the subgroup comparing robot-assisted gait training, MTT and physiotherapy revealed the following results: (1) For the activity counts of the arms: $F_{CountsArms}(2, 2921) = 97.40$, $p<0.001$, $\eta_p^2 = 0.063$. Post-hoc tests revealed that robot-assisted gait training showed significantly fewer activity counts of the arms compared to MTT and physiotherapy ($p<0.001$). (2) For the activity counts of the legs: $F_{CountsLegs}(2, 2921) = 209.20$, $p<0.001$, $\eta_p^2 = 0.125$. Post-hoc tests showed differences in intensity between all three therapies ($p<0.001$, robot-assisted gait training > MTT > physiotherapy). (3) For relative heart rate: $F_{HeartRate}(2, 1428) = 3.71$, $p=0.025$, $\eta_p^2 = 0.005$. Post-hoc tests revealed that relative heart rate was lower during robot-assisted gait training compared to MTT ($p=0.02$).

MTT vs. sports therapies (N=4)

Analyses of the subgroup comparing MTT and the sports therapies revealed the following results: (1) For the activity counts of the arms: $F_{CountsArms}(2, 2061) = 86.34$, $p<0.001$, $\eta_p^2 = 0.077$. Post-hoc tests revealed that both sports therapies elicited significantly more activity counts of the arms compared to MTT ($p<0.001$). (2) For the activity counts of the legs: $F_{CountsLegs}(2, 2042) = 72.38$, $p<0.001$, $\eta_p^2 = 0.066$. Post-hoc tests showed differences in intensity between all three therapies ($p<0.001$, Run&Fun > PluSport > MTT). (3) For relative heart rate: $F_{HeartRate}(2, 1009) = 44.98$, $p<0.001$, $\eta_p^2 = 0.082$. Post-hoc tests revealed that relative heart rate was lower during MTT compared to both sports therapies ($p<0.001$).

Differences between functional levels during Medical Training Therapy

We analyzed the differences in activity counts and heart rate between functional levels only for MTT, because each participant completed this therapy. The other therapies had too small subgroups to perform analyses between different GMFCS levels (see Supplemental Digital Content 2, http://links.lww.com/PHM/A894). Figure 3 provides an overview of the comparisons across GMFCS-levels. The effect for the activity counts of the arms was: $F_{CountsArms}(2,1181) = 80.55$, $p<0.001$, $\eta_p^2 = 0.120$. Post-hoc tests showed that participants with GMFCS level I reached significantly more activity counts of the arms compared to those classified as GMFCS level II or III ($p<0.001$). For the legs, the following result was obtained: $F_{CountsLegs}(2,1181) = 133.72$, $p<0.001$, $\eta_p^2 = 0.185$. Post-hoc tests showed significant differences between all GMFCS levels ($p<0.001$, most activity counts for level I and least activity counts for level III). The effect for the heart rate was: $F_{HeartRate}(2,1181) = 7.24$, $p = 0.001$, $\eta_p^2 = 0.012$. Post-hoc tests revealed a significant difference only between participants with GMFCS levels I and II ($p<0.001$).

Discussion

This cross-sectional pilot study confirms that different therapies elicit different levels of intensity (as highlighted in Figure 2) which are unrelated to the duration of those therapies (shown in Figure 1). Both figures provide exemplary indications that the duration of a therapy is an invalid proxy for the intensity of an intervention and should accordingly not exclusively be used to establish a dose-response relationship.

In biomechanics, ‘intensity’ refers to the measured amount of external work and/or power. Only when the mechanical output of a physical activity is quantifiable (e.g. on a cycle ergometer), the exact dose (or rate of energy expenditure) of the required task can be calculated.[13] This is neither feasible nor desirable when establishing dose-response relationships during motor rehabilitation in children with neuromotor disorders (or in adult populations, for that matter). Nevertheless, it is necessary to somehow include the intensity of a therapy into the calculation of the applied dose, as this increases the precision of this calculation. From a scientific point of view, this precision should be strived for, as the discussion around the sensitivity of outcome measures in large multicenter clinical trials showed.[31,32] This pilot study reveals, that the differentiation of the intensity of a therapy is possible and clinically feasible with accelerometers and a heart rate monitor.

Relation between therapy duration and intensity

Figure 1 nicely shows that there is no significant positive relationship between the duration of a specific therapy and its intensity. However, when looking at all data points, irrespective of which therapy they belong to, a "sham" correlation is apparent. This is mainly due to the combination of a clustering effect of the low intensity therapies (robot-assisted gait training, MTT and physiotherapy) and the significantly longer therapy duration of the sports therapy PluSport. Furthermore, it is noteworthy that the sports therapy Run&Fun showed a significant negative correlation between average intensity and duration. We attribute this to the high intensity of this therapy, where the effects of fatigue might play a significant role over time.

Differences among therapies

The results generally showed that sports therapies were associated with the highest intensities for both heart rate and activity counts of the arms as well as the legs. The highest variability in intensity could be observed for MTT.

The analyses of the two subgroups revealed many differences between several therapies and each therapy showed a distinct intensity pattern:

- In robot-assisted treadmill training, the goal is a high number of step repetitions, but cardiovascular intensity is generally not very high.[17] This is in line with our data. Nevertheless, the aim is to maximize the number of steps even though walking speed usually is rather low. Still, activity counts of the legs were more frequent compared to MTT or physiotherapy (Fig. 2). However, a differentiation between the active input of the participant and that of the robot itself is not possible and therefore, these data have to be critically appraised.
- MTT showed a higher level of activity counts of the legs compared to physiotherapy which might be due to higher numbers of repetitions that are usually performed during MTT where the focus lies on isolated strength, endurance and coordination exercises.[33] However, the intensity of MTT depends very much on the exercises performed and as such, MTT had the highest variability in intensity.
- Intensity during physiotherapy was the lowest when looking at the activity counts of the legs. This makes sense, as physiotherapy primarily focuses on the quality of walking-related movements and on regaining or improving functions and activities of daily living.[34] However, intensity during physiotherapy obviously depends very much on the task trained.
- The main emphasis of the sports therapies is to maximize whole-body physical activity and, specifically, to challenge the cardiovascular system.[35] Accordingly, intensity during sports therapies were significantly higher compared to the other therapies. Apart from the

different positioning of sports therapies in general, they are conducted in groups whereas in the other therapeutic interventions, patients work in an individual one-to-one situation with a therapist. Accordingly, peer effects could lead to a higher motivation[36] and, as a consequence, higher participation.

The intensity of a therapy is not only defined by the therapy itself but naturally also by the physical limitations of the participants that visit the therapies. Even though all selected therapies can be described as activity-promoting, it is obvious, that not all therapies address the same patient groups. Supplemental Digital Content 2 (http://links.lww.com/PHM/A894) shows that sports therapies were rather visited by functionally better participants, whereas robot-assisted gait training and physiotherapy were predominantly attended by participants with GMFCS levels II and III. This can also quantitatively be determined by looking at Table 3 and comparing the average values of MTT of both subgroups. To further highlight that the level of physical disability of a participant is a determining factor for the therapy's intensity, we've analyzed activity counts and heart rate during MTT which was attended by all our participants.

Differences among functional levels

For MTT, we found significant differences in activity counts and heart rate between participants classified at GMFCS level I compared to level II. This is in contrast to earlier publications,[37–39]. A possible explanation might be that in children with GMFCS level I, MTT focuses on a broader set of muscles and includes more coordinative exercises, which would positively influence activity counts and heart rate. With respect to the activity counts, there were also differences between participants with GMFCS level I and III. However, there were no differences between participants with GMFCS level II and III. Overall, we could confirm the tendency observed by Bjornson et al. (2007) that a lower functional level was linked to a lower physical activity.[37]

Limitations of the study

Even though we performed multiple measures per participant (an average of 6.5 therapy sessions of 30-75 minutes per child with approximately 2 million activity count data points per hour and 3600 heart rate data points per hour), the small sample size presents a clear limitation. We opted for increasing statistical power by using the means of every single minute instead of one overall average for each therapy. Another limitation is that sports therapies in their current form in our center are intended mainly for patients with GMFCS level I and II (except for a designated "wheelchair group"). This led to an overrepresentation of functionally better participants compared to the other therapies. Efforts should be undertaken to develop sports therapies where patients with GMFCS levels III can achieve higher intensity levels.

Replication of this study is not easily possible, since this was an observational study, and we did not want to influence participants nor therapists.

A further limitation was the adaptation of the Shuttle Run III protocol. Due to the shorter distance, the participants had to accelerate, decelerate, and change the direction more often. This might have led to test abandonment due to maneuvering issues rather than cardiovascular limitations. Finally, not all participants where measured within the projected 2 weeks due to clinical everyday life (e.g. external examinations of the patients, cancellation of therapies, last-minute rescheduling, see Supplemental Digital Content 2, http://links.lww.com/PHM/A894). However, since this only occurred in participants who showed relatively mild motor deficits, we assumed their physical condition to remain constant and therefore all measurements were included in our analysis.

Conclusion

This study highlights that different therapies elicit different levels of intensity in children with neuromotor disorders. These intensity levels can be pragmatically assessed with accelerometers and a heart rate monitor in children with neuromotor disorders. Finally, we recommend against using the duration of a therapy as a proxy for the dose to make statements about dose-response relationships.

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Figure legends

Figure 1: Scatter plots displaying the relation between average intensity and therapy duration for the activity counts of the arms (top panel), the activity counts of the legs (middle panel) and for relative heart rate (bottom panel).

Abbreviations: **MTT** medical training therapy

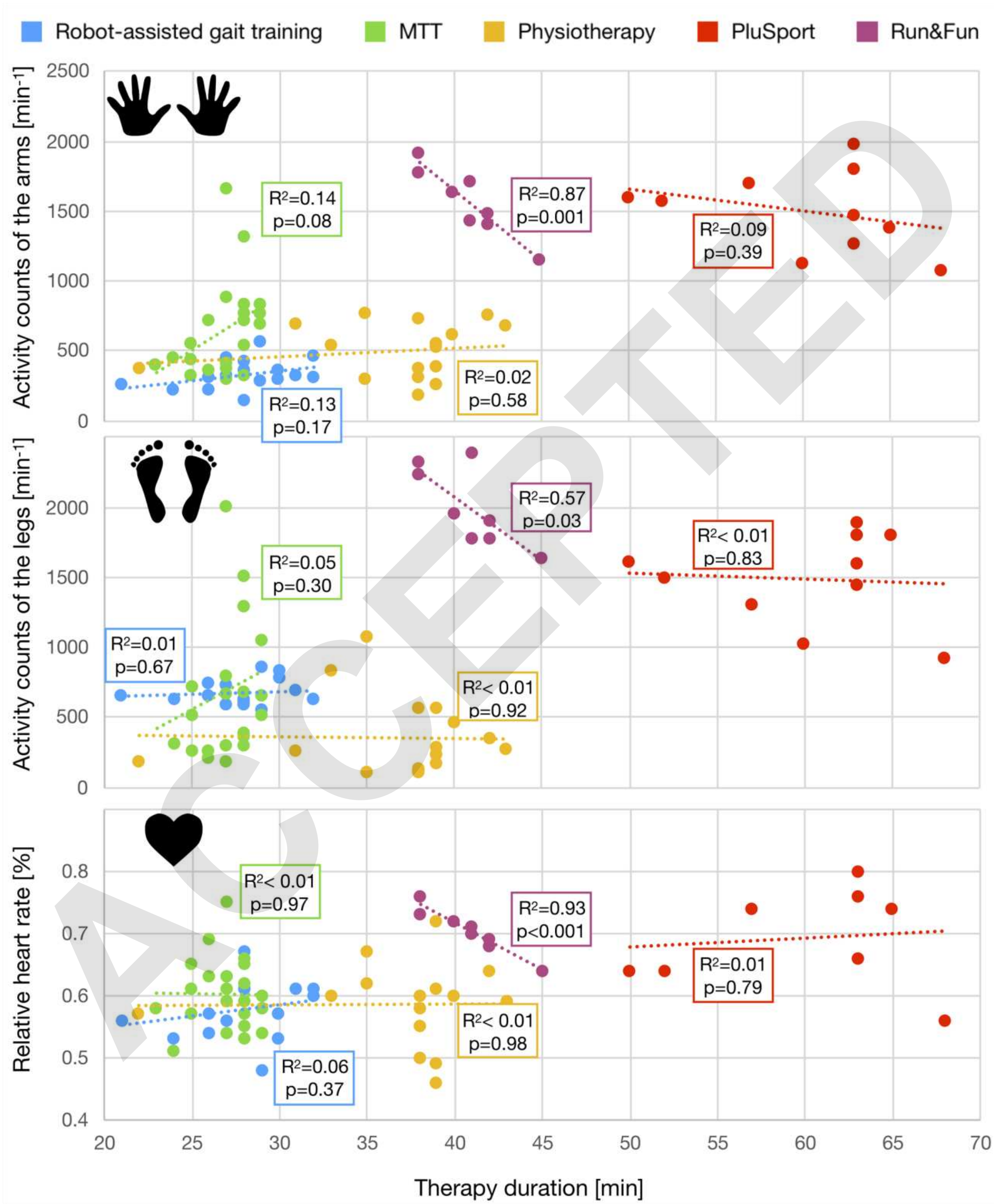
Figure 2: Average intensity for each therapy per participant, subdivided by activity counts of the arms (top panel), activity counts of the legs (middle panel) and relative heart rate (bottom panel). All values are individually normalized to MTT.

Abbreviations: **MTT** medical training therapy

Figure 3: Activity counts and heart rate per functional level (GMFCS) during medical training therapy.

Abbreviations: **GMFCS** Gross Motor Function Classification System; *** $p<0.001$

Figure 1



Robot-assisted gait training
MTT
Physiotherapy
PluSport
Run&Fun
Activity counts of the arms [min-1]
2500
2000
1500
1000
500
0
R²=0.14
p=0.08
R²=0.87
p=0.001
R²=0.09
p=0.39
R²=0.02
p=0.58
R²=0.13
p=0.17
Activity counts of the legs [min-1]
2000
1500
1000
500
0
R²=0.57
p=0.03
R²< 0.01
p=0.83
R²=0.05
p=0.30
R²=0.01
p=0.67
R²< 0.01
p=0.92
Relative heart rate [%]
0.8
0.7
0.6
0.5
0.4
R²< 0.01
p=0.97
R²=0.93
p<0.001
R²=0.01
p=0.79
R²< 0.01
p=0.98
R²=0.06
p=0.37
20 25 30 35 40 45 50 55 60 65 70
Therapy duration [min]
ACCEPTED

Figure 2

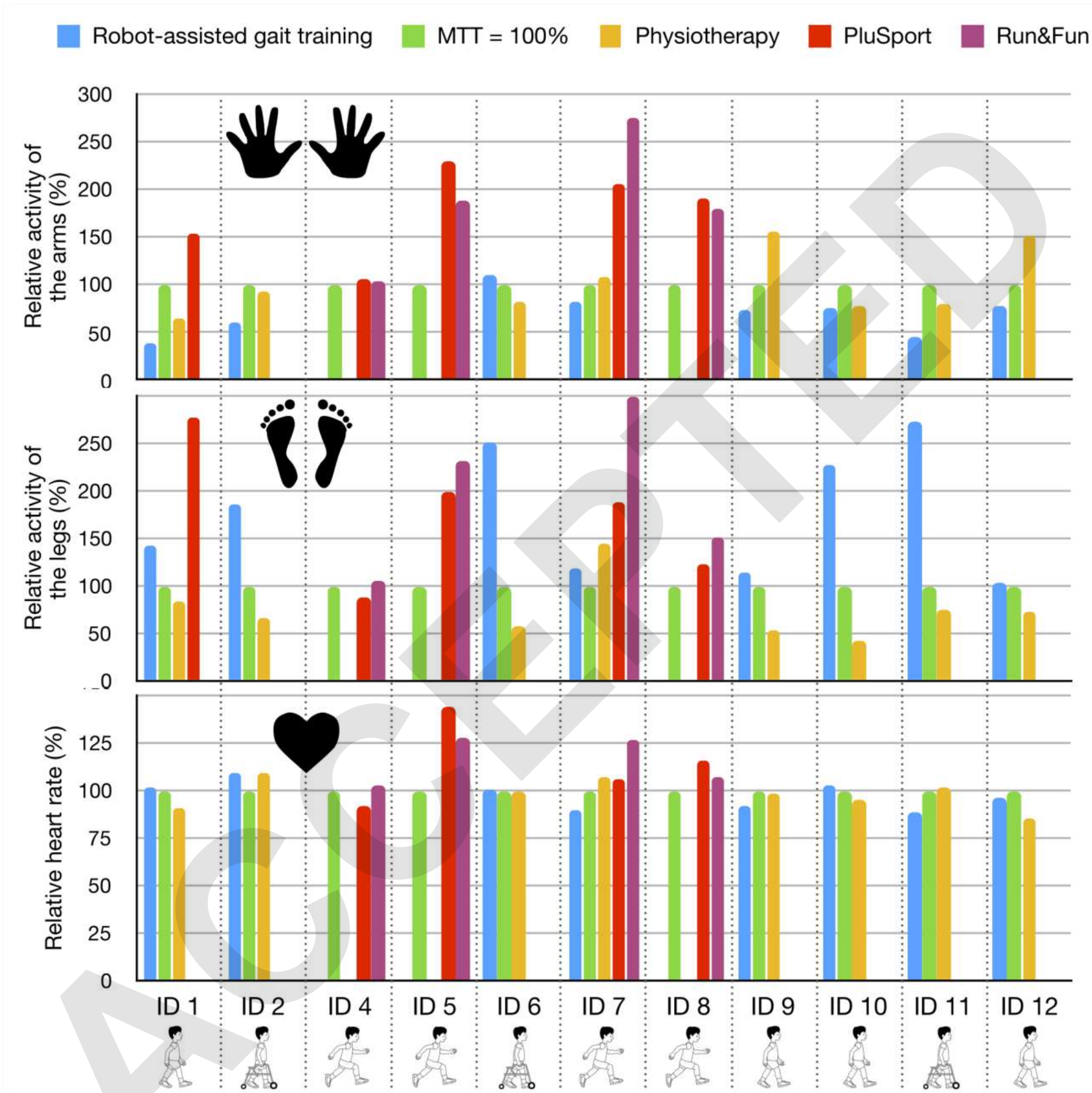
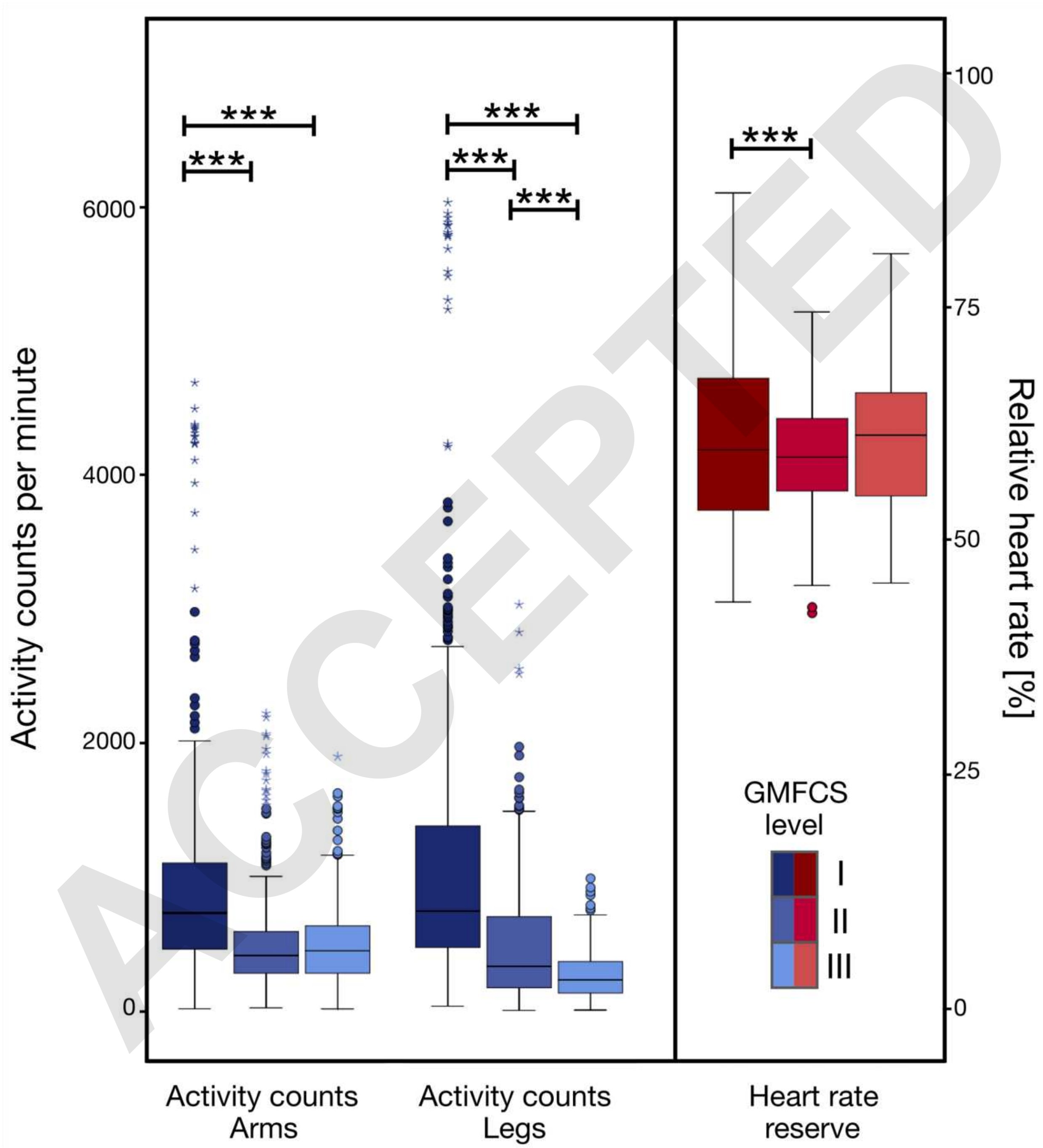

Robot-assisted gait training
MTT = 100%
Physiotherapy
PluSport
Run&Fun
Relative activity of the arms (%)
Relative activity of the legs (%)
Relative heart rate (%)
300
250
200
150
100
50
0
125
75
25
ID 1
ID 2
ID 4
ID 5
ID 6
ID 7
ID 8
ID 9
ID 10
ID 11
ID 12

Figure 3



Activity counts per minute
6000
4000
2000
0
***
***
***
***
***
***
100
75
50
25
0
Relative heart rate [%]
GMFCS level
I
II
III
Activity counts Arms
Activity counts Legs
Heart rate reserve

Table 1: Shuttle Run protocols (adapted from [27]).

Mode of locomotion	Protocol	Distance	Start speed	Increase per min
Able to run	SRT I	10 m line	5 km/h	0.25 km/h
Independent walking	SRT II	10 m line	2 km/h	0.25 km/h
Using assistive devices	SRT III	5 m square*	1.5 km/h	0.19 km/h
Wheelchair users	SRiT	10 m line	2 km/h	0.25 km/h

Abbreviations: **SRT** Shuttle Run Test, **SRiT** Shuttle Ride Test. *The Shuttle Run III protocol was modified from a 7.5-meter to a 5-meter square due to space restrictions in our center (the respective sound file was accordingly adapted).

Table 2: Participants' characteristics

	Sex	Age [yrs]	Diagnosis	Mobility	FAC	GMFCS level	10mWT [s]	1SPT [m]	HRrest [bpm]	HRmax [bpm]
ID01	f	13	hemiparesis	walk	5	II	7.8	nt	83	204
ID02	m	9	spastic CP	wheelchair	4	III	nt	5.93	89	194**
ID03*	m	11	stroke	run	5	I	8.5	nt	93	nt
ID04	m	13	TBI	run	5	I	8.2	nt	76	214
ID05	m	15	hemiparesis	run	5	I	6.7	nt	77	210
ID06	f	11	spastic CP	walker	3	III	26.0	nt	105	194**
ID07	m	13	stroke	run	5	I	7.2	nt	79	209
ID08	f	11	encephalopathy	run	5	I	10.2	nt	82	198
ID09	m	15	ataxic CP	walker	4	II	10.6	nt	86	194**
ID10	f	12	spastic CP	crutches	5	II	15.1	nt	89	194**
ID11	m	10	spastic CP	walker	4	III	25.7	nt	89	184
ID12	f	16	polyneuropathy	walker	5	II	11.9	nt	89	194**

Abbreviations: **ID** Identification number; **FAC** Functional Ambulation Category; **GMFCS** Gross Motor Function Classification System; **10mWT** 10-meter Walk Test normal speed; **1SPT** 1-Stroke Push Test; **HRrest** resting heart rate; **HRmax** maximal heart rate; **f** girl; **m** boy; **CP** cerebral palsy; **TBI** traumatic brain injury; **nt** not tested; *dropout; **test was not maximal.

Table 3: Average intensities of therapies in subgroup analyses.

	Activity counts of arms (mean±SD)	Activity counts of legs (mean±SD)	Relative heart rate (mean±SD)
Subgroup 1			
Robot-assisted gait training	332±219	673±160	0.58±0.05
MTT	511±360	441±430	0.59±0.07
Physiotherapy	503±333	352±408	0.59±0.09
Subgroup 2			
MTT	924±803	1150±1177	0.61±0.10
PluSport	1563±825	1539±1013	0.69±0.13
Run&Fun	1549±1063	1982±1291	0.70±0.11

Abbreviations: **MTT** Medical training therapy; **SD** Standard deviation